Uncertainty Quantification of Prompt Fission Neutrons Spectra

Patrick Talou, David G. Madland, Toshihiko Kawano, T-2

The nuclear fission process is usually accompanied by the emission of neutrons and γ-rays. Indeed, right after scission, the two (or more) primary fission fragments are in excited states due to collective as well as intrinsic excitations. In turn, they release this excitation energy to get back to their ground or an isomeric state by emitting neutrons and γ-rays. Those are called prompt (strong interaction) to distinguish them from the delayed neutrons and γ-rays, which get emitted later by the nuclei that have been formed following the β-decay (weak interaction) of the fission products (after prompt neutron emission).

Both prompt and β-delayed neutrons play crucial roles in nuclear reactors. As the world is designing new and advanced fast nuclear reactors, a precise knowledge of the spectrum and the average multiplicity of neutrons is absolutely necessary. In addition, an accurate evaluation of the uncertainties associated with those quantities is needed to estimate the impact of current knowledge on the simulated quantities of interest for reactor design.

A very common and successful tool for evaluating the prompt fission neutrons spectrum (PFNS) is to use the so-called Los Alamos model developed by D. G. Madland and J. R. Nix at LANL [1]. In this model, the PFNS is calculated from a sampling of the most important fission fragments produced in a given fission process (for a specific isotope and incident neutron energy), and represents an average of all possible neutron emissions over an initial temperature distribution in the primary fragments. With only a few adjustable parameters, the PFNS for incident neutrons below 20 MeV on any fissioning isotope can be calculated with reasonable accuracy.

Our present efforts aim at quantifying the uncertainties associated with the calculated spectra for isotopes important to the Advanced Fuel Cycle Initiative (AFCI). These uncertainties can then be propagated using transport codes such as Monte Carlo N-Particle code (MCNP) and their impact on the overall design, safety, and efficiency of a reactor can be assessed.

In the present approach, uncertainties in the PFNS are evaluated using both experimental data and model calculations. First, Los Alamos model calculations are performed to best represent available experimental data (if any). Then, sensitivity coefficients are obtained by varying the model parameters around their central values. On the other hand, experimental data sets are analyzed and an experimental covariance matrix, containing both standard deviations and correlations, is produced from known or estimated statistical and systematic uncertainties. The final result is obtained by combining experimental and theoretical results using a Bayesian Kalman filtering technique.

Figure 1 shows the evaluated standard deviations obtained for the PFNS of 0.5 MeV neutron-induced fission of ^{239}Pu. The red curve (times 100!) depicts the result when no experimental data is used, and only *prior* uncertainties

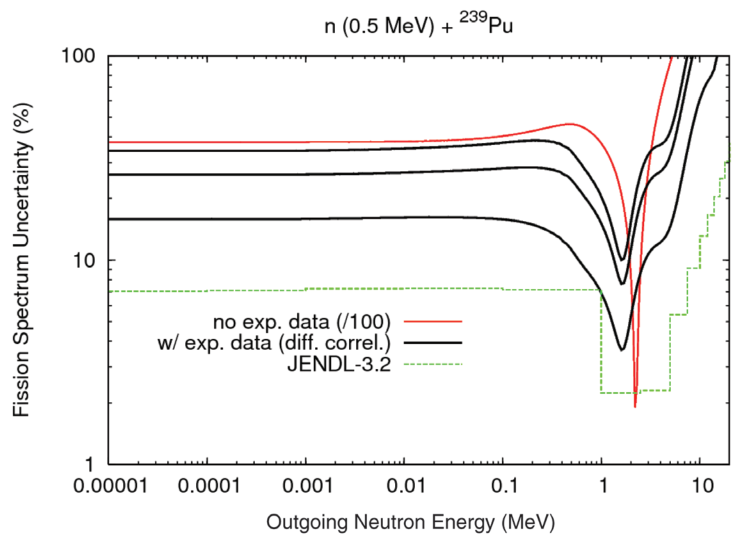

Fig. 1. PFNS standard deviations (in %) for the neutron-induced fission reaction on ^{239}Pu for incident neutron energy $E_n = 0.5$ MeV. See text for explanations.

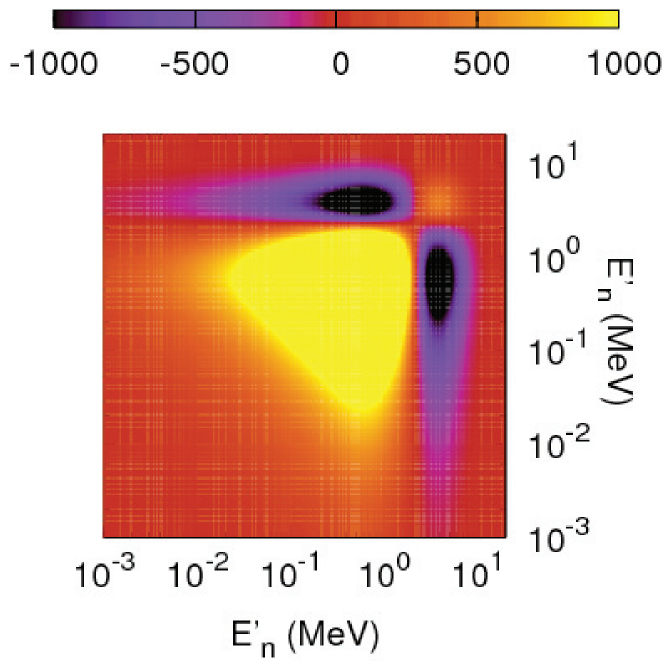

Fig. 2. Final correlation matrix evaluated for the reaction $n(0.5MeV) + {}^{239}Pu$. Correlation matrix coefficients span the [-1000,1000] interval. A stringent physical requirement is that the PFNS is normalized to unity. This is the primary reason for the negative terms (purple and black regions) in this matrix.

are assumed for the model parameters. The very large uncertainties are due to the great sensitivity of the result to the total excitation energy available in the system, a quantity which stems from the difference between two large numbers: average energy release minus average total kinetic energy. With further constraints from experimentally measured spectra, the standard deviations drop significantly, as shown with the three black curves, which correspond to three different assumptions for the experimental covariance matrix.

The dip appearing on all these curves occurs just below the average energy of the spectrum, which is the most well-known quantity experimentally. However, uncertainties in the tails of the spectrum are evaluated at more than 15%, which is quite significant for the simulation of reactors. A similar Japanese work is also shown in green (JENDL-3.2) and does not exhibit such large uncertainties, albeit they are still nonnegligible.

The covariance matrix obtained is shown in Fig. 2. Regions in black correspond to negative terms characteristics of anticorrelation factors. They are primarily due to the physical requirement that the PFNS be normalized to unity.

Further work will include more experimental data sets, other important isotopes (^{235,238}U), and a study of the model errors. In particular, the Los Alamos model is based on several physical assumptions, which may have to become more detailed in view of new experimental data, especially in the low-energy part of the spectrum where experimental data are scarce. Also, new model calculations based on the statistical decay theory of the excited fission fragments are being pursued, and may constitute a very promising tool to go beyond our current model [2].

Preliminary results of the uncertainty quantification work can be found in [3].

For further information contact Patrick Talou at talou@lanl.gov.

[1] D.G.Madland, J.R. Nix, *Nucl. Sci. Eng.* **81,** 213-271 (1982).
[2] P. Talou, in *Proceedings of the International Conference on Nuclear Data for Science & Technology,* ND2007, April 2007, Nice, France, EDP Sciences, 317 (2008).
[3] P. Talou, D.G. Madland, T. Kawano, *Nuclear Data Sheets* **109,** 2858 (2008).

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